Using Satellite Observations of Cloud Vertical Distribution to Improve Global Model Estimates of Cloud Radiative Effect on Key Tropospheric Oxidants

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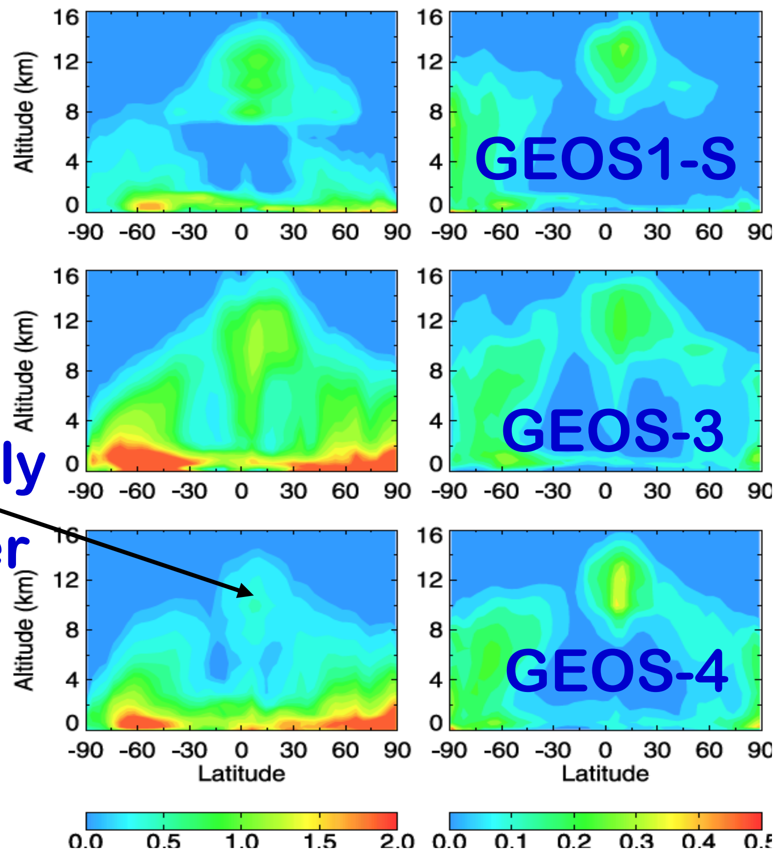
Outline

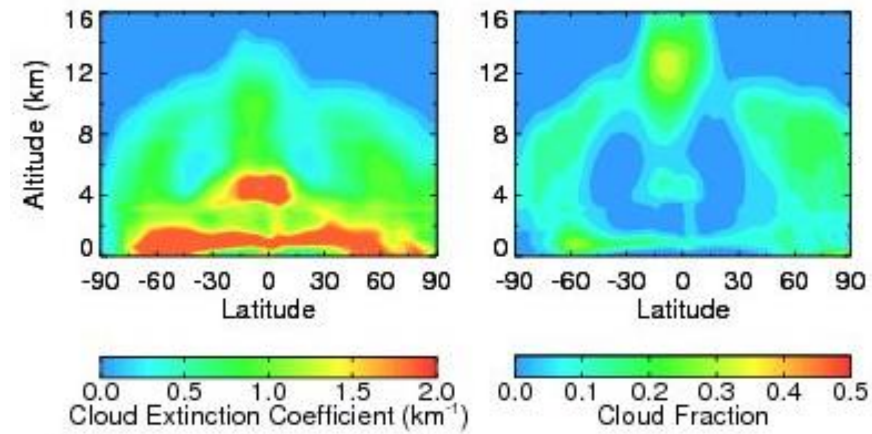
- Motivation & Objectives
- CCCM – a merged satellite cloud data product
- GEOS-Chem / MERRA (Fast-J, cloud overlap)
- MERRA cloud and evaluation with CCCM
- Radiative effect of clouds in G-C/MERRA
- Using CCCM to constrain model clouds & effects
- Summary & Conclusions

Large Differences in Cloud Distribution Among Models



Cloud Ext. Coefficient Cloud Fraction (June)

MERRA



- **Radiative impact of clouds on global photolysis frequencies and OH is more sensitive to the vertical distribution of clouds than to the magnitude of column CODs [Liu, H. et al., JGR 2006, 2009].**

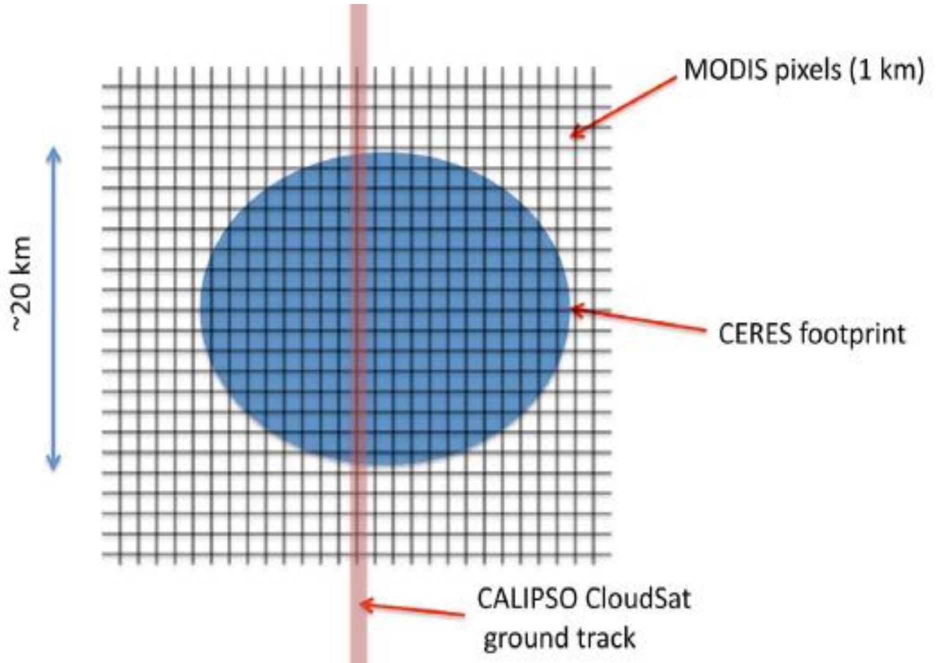
Objectives

- To ***evaluate*** GEOS-Chem/MERRA model clouds and their vertical distribution with A-Train satellite observations.
- To ***quantify*** the impact of model biases in cloud optical depths and spatial distributions on the simulated key tropospheric oxidants.

CCCM – a Merged Cloud Data Product @ NASA Langley

Merged cloud vertical profiles from multiple A-Train satellite (CALIPSO, CloudSat, CERES, and MODIS) observations (Kato et al., JGR 2010, 2011)

- Collocation of 333-m CALIPSO and 1-km CloudSat mask profiles to 1-km MODIS pixel.
- The merged cloud profiles are further collocated & grouped within a 20-km CERES footprint.
- 3-D structures of cloud boundary, cloud extinction, ice/liquid water contents, and cloud fraction.



GEOS-Chem Global Chemical Transport Model (v9.2, http://geos-chem.org/)

- Driven by the MERRA reanalysis from NASA GMAO
- Horizontal resolution 2°×2.5°, 47 levels in vertical

- Ozone-NO_x-CO-VOC coupled to aerosol (sulfate-nitrate-ammonium and carbonaceous) chemistry [Bey et al., 2001; Park et al., 2004]
- Photolysis rate calculation: **Fast-J** [Wild et al., 2000] with MERRA surface albedo, 3-D cloud optical depth, and cloud fraction

- Simulation period: Sept.2007 – **Jan.2008** (to be continued to Dec 2008)

Model Representations of Cloud Vertical Coherence

- **Linear Assumption**

$$\tau_c' = \tau_c \cdot f$$

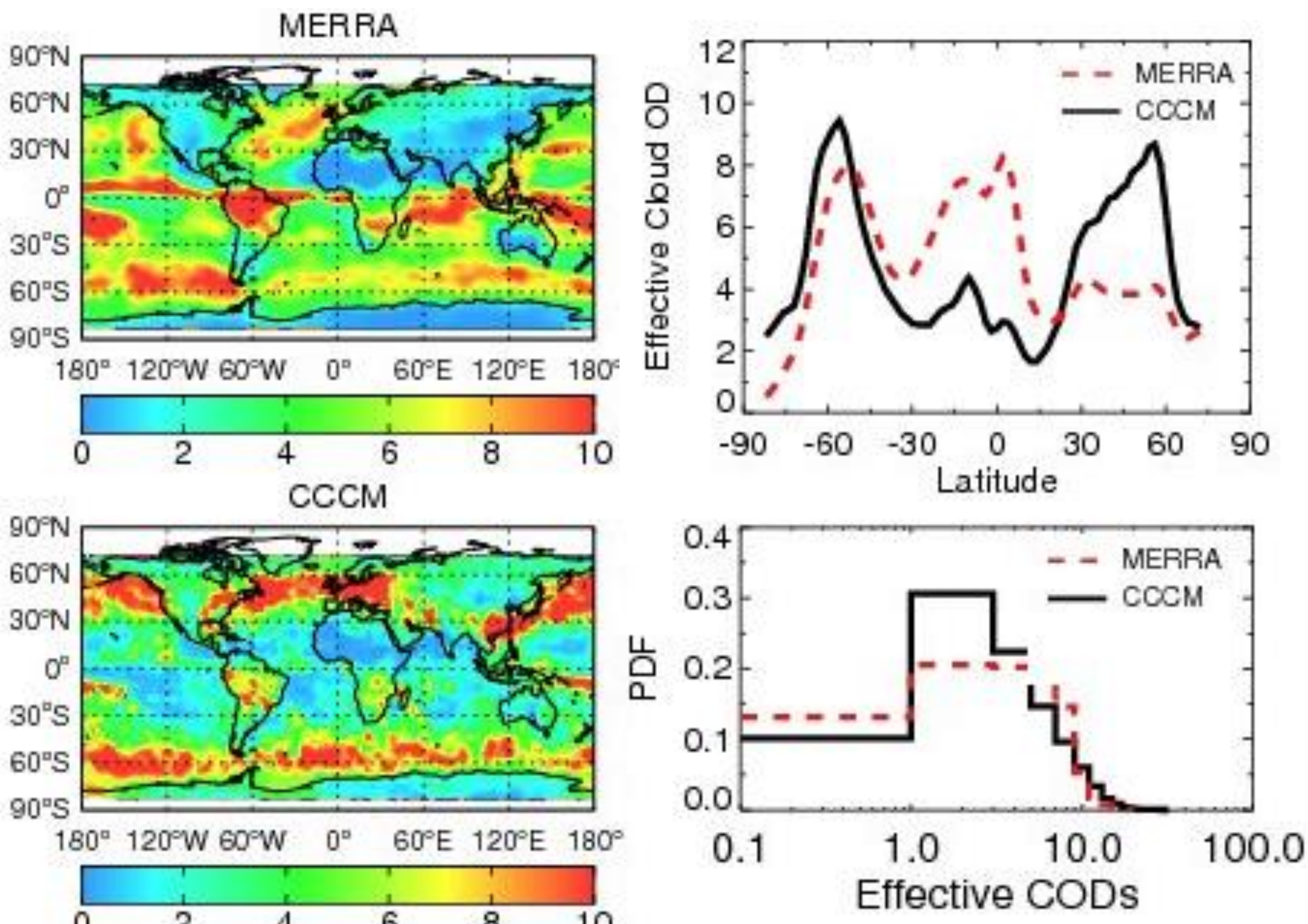
grid-scale OD　　in-cloud OD　　cloud fraction

- **Approximate Random Overlap** **[Briegleb, 1992]**

$$\boldsymbol{\tau_c' = \tau_c \cdot f^{3/2}} \rightarrow \textbf{Effective COD}$$

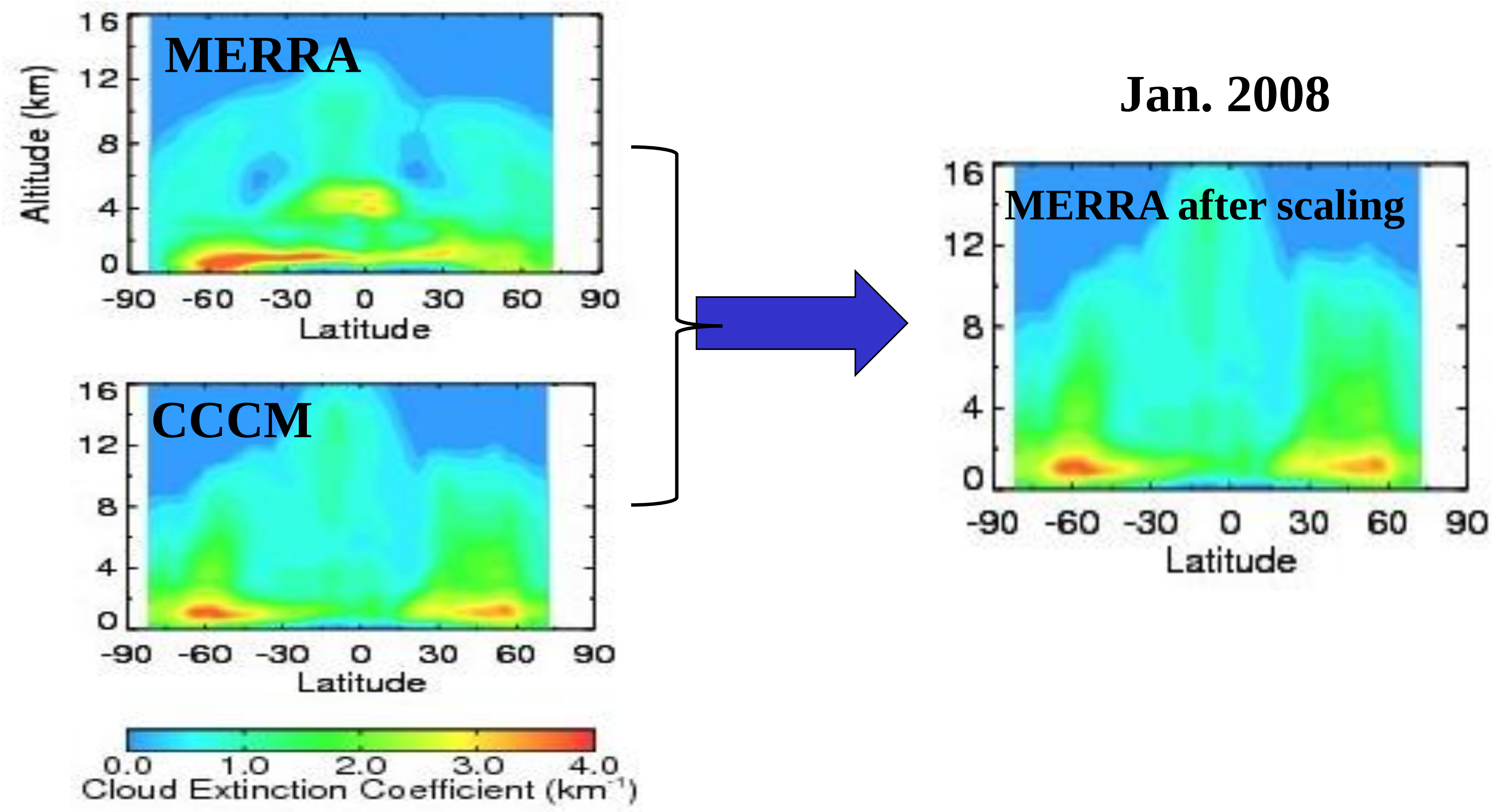
- **Maximum-Random Overlap** **[Stubenrauch et al., 1997]**
  - clouds in adjacent layers (a cloud block) are maximally overlapped; cloud blocks are randomly overlapped.

Global Distribution of Effective Cloud Optical Depth
MERRA vs. CCCM (Jan. 2008)



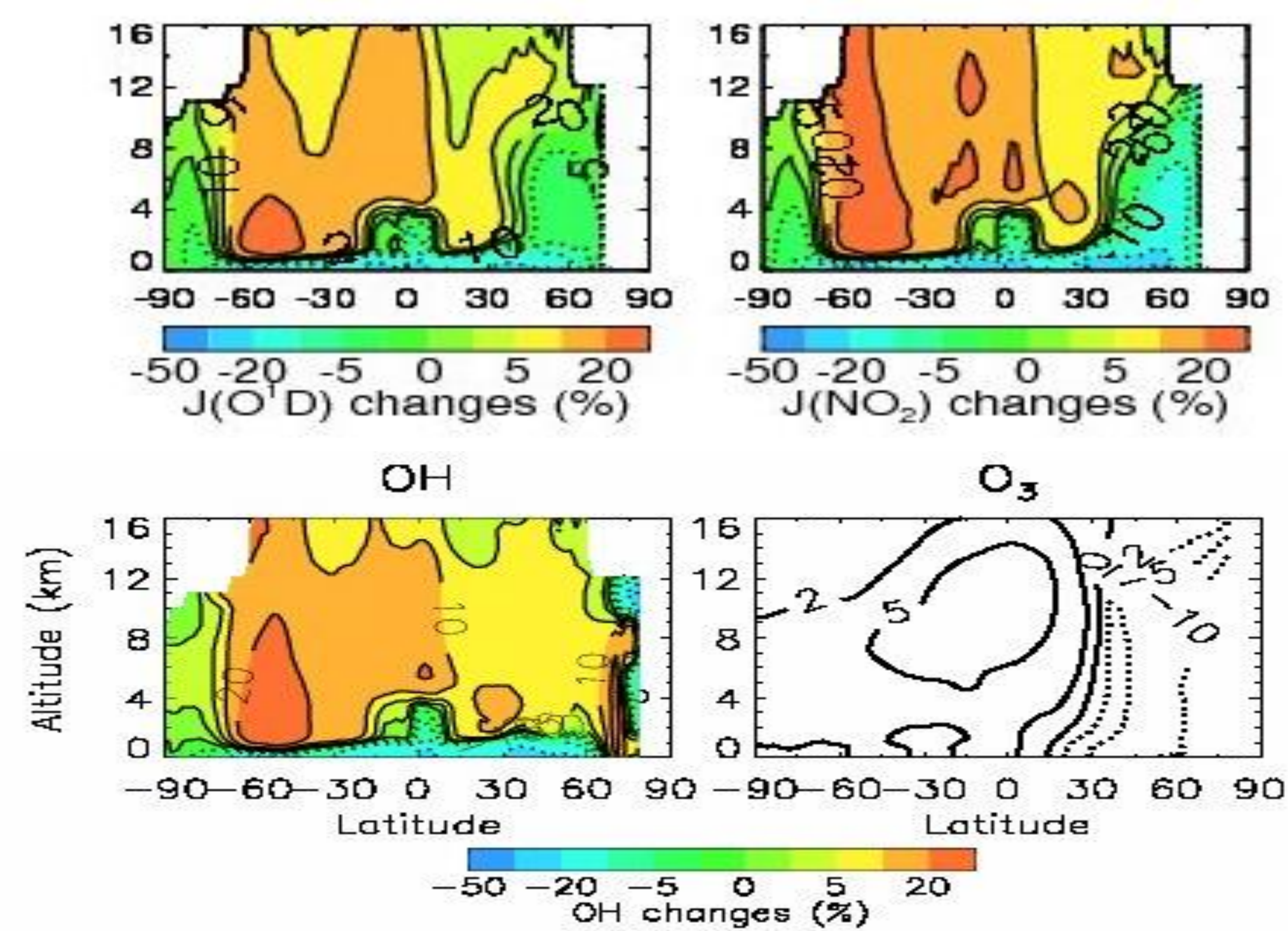
- MERRA daily 1:30pm LT clouds sampled along satellite orbit track.
- MERRA overestimates tropical cloud OD, but underestimates at NH mid-lat.

Scale MERRA 3-D Effective Cloud ODs to Those of CCCM on a Monthly Mean Basis



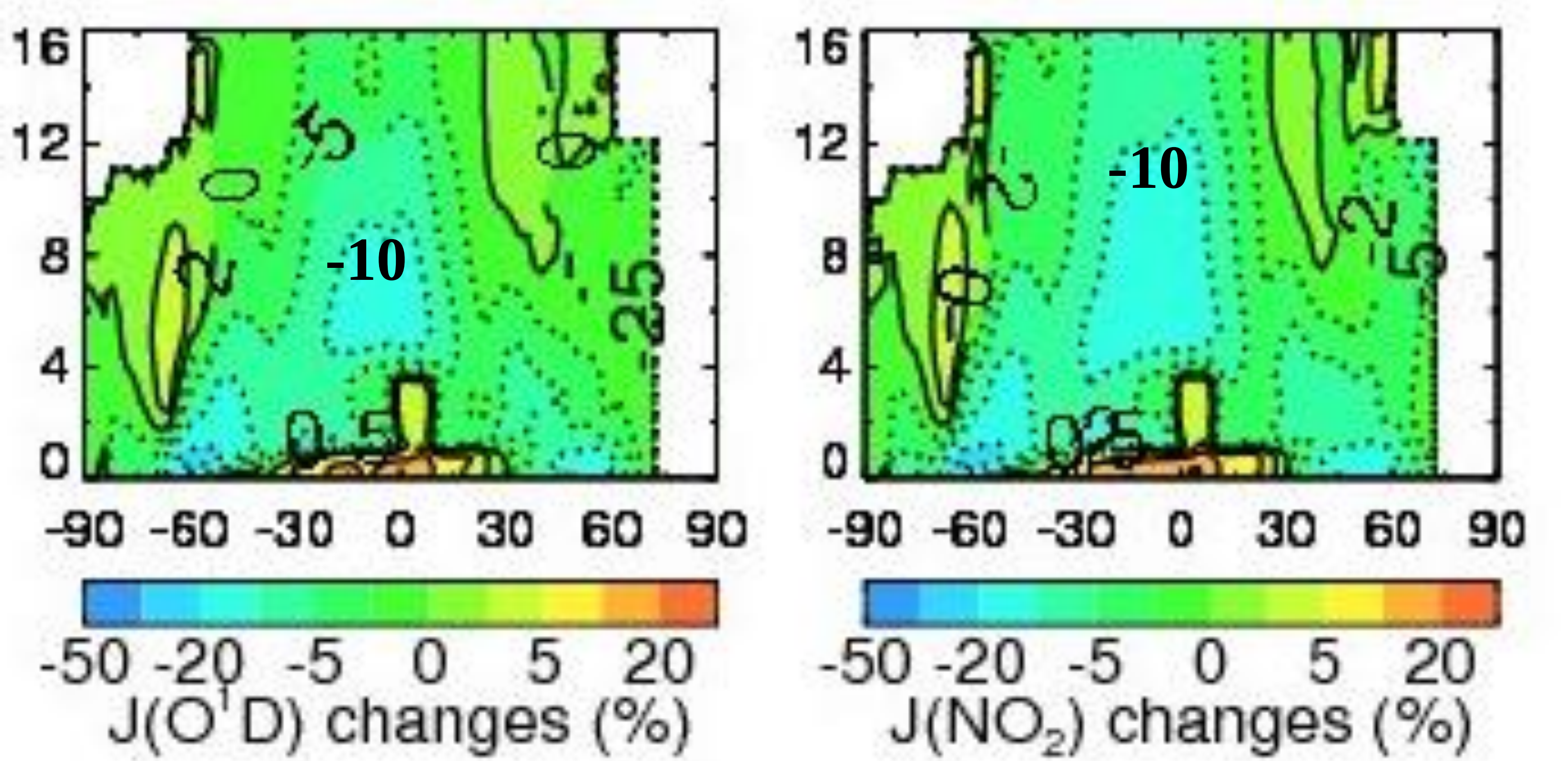
- Monthly 3-D scale factors are applied to model instantaneous effective ODs for that month.

Changes (%) in Daily Mean J-values, OH and O_3 Due to Cloud (G-C / MERRA, Jan. 2008)



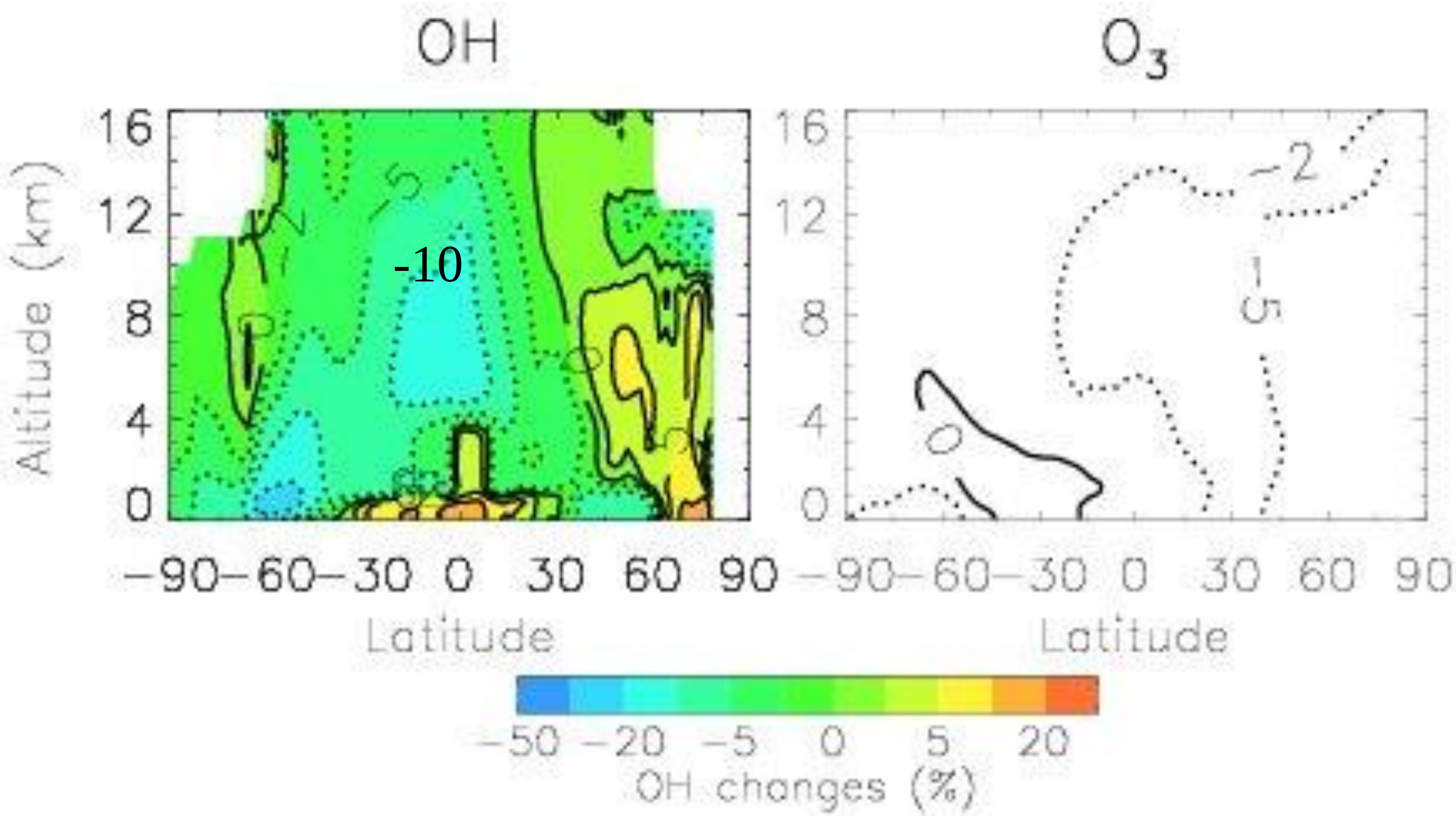
- **Large increases in J-values and OH in tropical MT / UT and in SH marine stratiform cloud region.**

Changes (%) in Daily Mean J-values Due to Cloud Adjustment (Jan. 2008)



- **Large decreases in $J(O^1D)$ and $J(NO_2)$ in tropical MT / UT and in SH marine stratiform cloud region.**

Changes (%) Due to Cloud Adjustment (Jan. 2008)



- **Global multi-model mean OH concentration is overestimated by 5-10% [Naik, V. et al., ACP 2013].**
- **Here, using CCCM to constrain the model clouds reduces the global mass-weighted mean OH concentration by ~5% in Jan.**

Summary and Conclusions

- **Radiative effect of clouds is one of the major factors that affect tropospheric OH. Large differences in cloud distributions among current (chemistry-climate or chemical transport) models could contribute significantly to the wide model spread of tropospheric OH, which was reported by the ACCMIP activity (Voulgarakis et al., ACP 2013).**

- **CCCM, a 3-D cloud data product developed at NASA Langley and merged from multiple A-Train satellite observations, provides unprecedentedly strong constraints on the vertical distribution of clouds and therefore simulated effects of clouds on key tropospheric oxidants.**

- **The approach presented here can be used in other CTM or CCM models (e.g., within the Chemistry-Climate Modeling Initiative) to reduce biases in model-simulated OH.**

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